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Events before the flash D*o* influence the flash-lag magnitude

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Abstract

The flash-lag effect occurs when a flash abreast of a smoothly moving object is perceived to spatially lag the moving object. The postdiction accounts of this effect assume either that the flash 'resets' motion detectors [Science 287 (2000) 2036], or that position information is not computed for moving objects until it is needed [Trends in the Neurosciences 25 (2002) 293], the latter view having also been proposed by Brenner and Smeets [Vision Research 40 (2000) 1645]. According to these accounts, events occurring before the flash should not change the magnitude of the flash-lag effect. In our experiment, pre-exposure of the moving object as a stationary stimulus, for as little as 50 ms before the flash occurred, significantly reduced the flash-lag effect.

Keywords: Flash-lag; Illusion; Postdiction; Motion; Spatial localisation

1. Introduction

The flash-lag effect occurs when a stimulus is flashed abreast of a smoothly moving object, but appears to spatially lag that moving object (Fig. 1). In order to appear to be aligned with the moving object, the flashed object must actually be displayed ahead of it. An agreed explanation for the flash-lag effect continues to be elusive (reviewed by Krekelberg & Lappe, 2001; Nijhawan, 2002; van de Grind, 2002) and so new accounts continue to be proposed (Eagleman & Sejnowski, 2002).

According to the original *postdiction* account of the flash-lag effect (Eagleman & Sejnowski, 2000a), stimulus motion after the flash is the critical factor in determining the size of the flash-lag effect. Prior motion is almost irrelevant, given their assumption that the flash resets motion detectors. In the face of evidence from Krekelberg and Lappe (2000b) and Whitney and Cavanagh (2000), Eagleman and Sejnowski (2000b) conceded that this might be a matter of degree, in the following sense: they argued that an internal model of the world, and in particular the moving object, is constructed by the observer, but the extent to which this contributes to perception of that object may vary. Specifically, an unexpected event such as a flash, being unaccounted for by the model, causes the model itself to be substantially discounted in favour of new information from the environment. However, if a flash is less salient, then more of the model is retained, and in particular information about the position of the moving object prior to the flash is not lost to the same extent. In common with a number of others (Krekelberg & Lappe, 2000a; Whitney, Murakami, & Cavanagh, 2000), Eagleman and Sejnowski also assume that information from position detectors is integrated over time. Their assumption that this process starts from the time of the flash necessarily means that the moving object's position will be determined to be ahead of that of the flash.

Recently, Eagleman and Sejnowski (2002) have rescinded the proposition that the flash resets motion detectors. Instead, they have adopted the view, first proposed by Brenner and Smeets (2000), that position information for a moving object is not generally available, as it is simply not needed most of the time. When position information is required, as is the case for participants in a flash-lag experiment, a separate position computation is performed, which is initiated by the flash. Again the moving object is perceived to be ahead of the flash as integration over a temporal window is still assumed.

We sought to test both postdiction accounts by modifying the flash initiated paradigm, in which the moving object appears co-instantaneously with the flash (Khurana & Nijhawan, 1995). A flash-lag effect is typically

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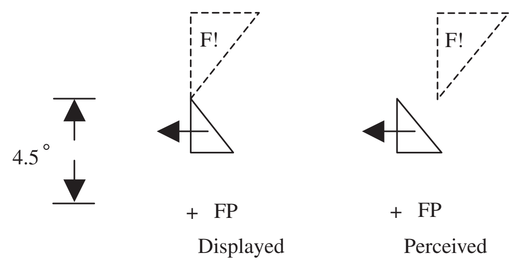

Fig. 1. Our flash-lag stimuli consisted of triangular objects. FP is the fixation point and F! indicates the flashed object. The moving triangle was 1.4° on its shorter sides and moved at 12°/s, while the flashed triangle was twice as large. The fixation point was 4.5° vertically below the upper point of the moving object. Stimuli were white with the moving object having luminance 155 Cd/m^2 and the flash 176 Cd/m^2 (the difference being due to luminance variation across the monitor). The background was black and close to 0 Cd/m^2 (all measurements by a Tektronix J18 luminance probe of 1° angle). Viewing distance was 57.3 cm.

observed with this arrangement (Eagleman & Sejnowski, 2000a). Our modification consisted of displaying the 'to-be-moving' object in one location for varying lengths of time before the flash appeared, at which time this object (which had been stationary) commenced moving. If the assumption regarding the irrelevance of events before the flash were strictly true, our manipulation would have no effect on the size of the flash-lag effect. However, we were inclined to believe that the window of integration would extend back in time before the flash, and thus we hypothesized that our manipulation would reduce the flash-lag effect. We note, however, that Whitney and Cavanagh (2000) performed a similar manipulation—they displayed their 'to-be-moving' object for 2.5 seconds, then removed it for 30 ms, and then it re-appeared and moved co-instantaneously with the flash. They found this manipulation had no effect on the flash-lag illusion's magnitude, when compared with a 'standard' flash-initiated-condition where no such pre-cuing occurred.

2. Participants and methods

The participants were four naïve students, one research assistant, and one of the authors. Participants were required to indicated if the vertical edge of the flash was to the left or to the right of the vertical edge of the moving object on each trial (see Fig. 1). This stimulus addressed concerns about phosphor decay (Jonides, Irwin, & Yantis, 1983)—on the front edges the phosphor ramps up very rapidly, reaching maximum luminance in approximately 20 μs (Wolf & Deubel, 1997). Eight conditions were randomly interleaved: the four pre-flash exposure times (0, 50, 250, and 750 ms) by two directions of motion—leftwards or rightwards. Participants had 1500 ms after the moving object finished traversing the screen in which to respond, after which time their response was not recorded.

Using an adaptive method of constant stimuli, a unique set of nine moving object/flashed object spatial offsets for each participant-condition were used at any one time. After approximately 18 trials per condition, and thereafter after every approximately nine trials per condition, the presentation software ran a logistic regression (Finney, 1971) for each condition, to find the moving object-flash point of subjective alignment for each participant and condition. The nine moving object-flash offsets were then adjusted for each condition, so as to be centred around that participant's point of subjective alignment—for data sets on which Fig. 2 is based they usually ranged about 0.8° on either side of the point of subjective alignment, generally ranging 0.5° on either side of it at any one time. This was sufficient to span the psychometric function. Average (Av.) data in Fig. 2 were normally based on 144 trials from one testing session, which followed a pilot session of 108 trials on a previous day. Only a handful of trials were lost through the 1500 ms timeout. Finney's (1971) methods were used to compute 95% confidence intervals.

3. Results

For all except one participant, the flash-lag effect was sufficiently large that the range of testing did not include the zero-offset point. Consequently there was no evidence, or even possibility, of 'clipping' at this point for five participants, and in fact it was not in evidence either for the participant whose testing range did include the zero offset point.

As shown in Fig. 2, the motion-from-the-left vs. motion-from-the-right data exhibited consistent differences for P2 and P3, whilst a number of other participants had a significant motion direction difference in at least one condition. However, the pattern as a function of pre-flash exposure time is essentially the same for all participants for both directions, so in testing our hypotheses we will only consider the data collapsed across both directions.

For five out of six participants, 50 or 250 ms of exposure to the moving object at rest before the flash occurred significantly reduced the flash-lag effect, compared to no exposure, as indicated by the confidence intervals for each participant in Fig. 2. [1] For 750 ms of exposure, only three out of six showed a significant reduction compared with no exposure. Analyses across participants yielded the same result—a significant reduction for 50 and 250 ms (six out of six showing a decrease, $p = 0.032$, two-tailed Binomial test), but not

[1] For a seventh participant this difference was also significant, but they were excluded because of unacceptably large confidence intervals for some directional data.

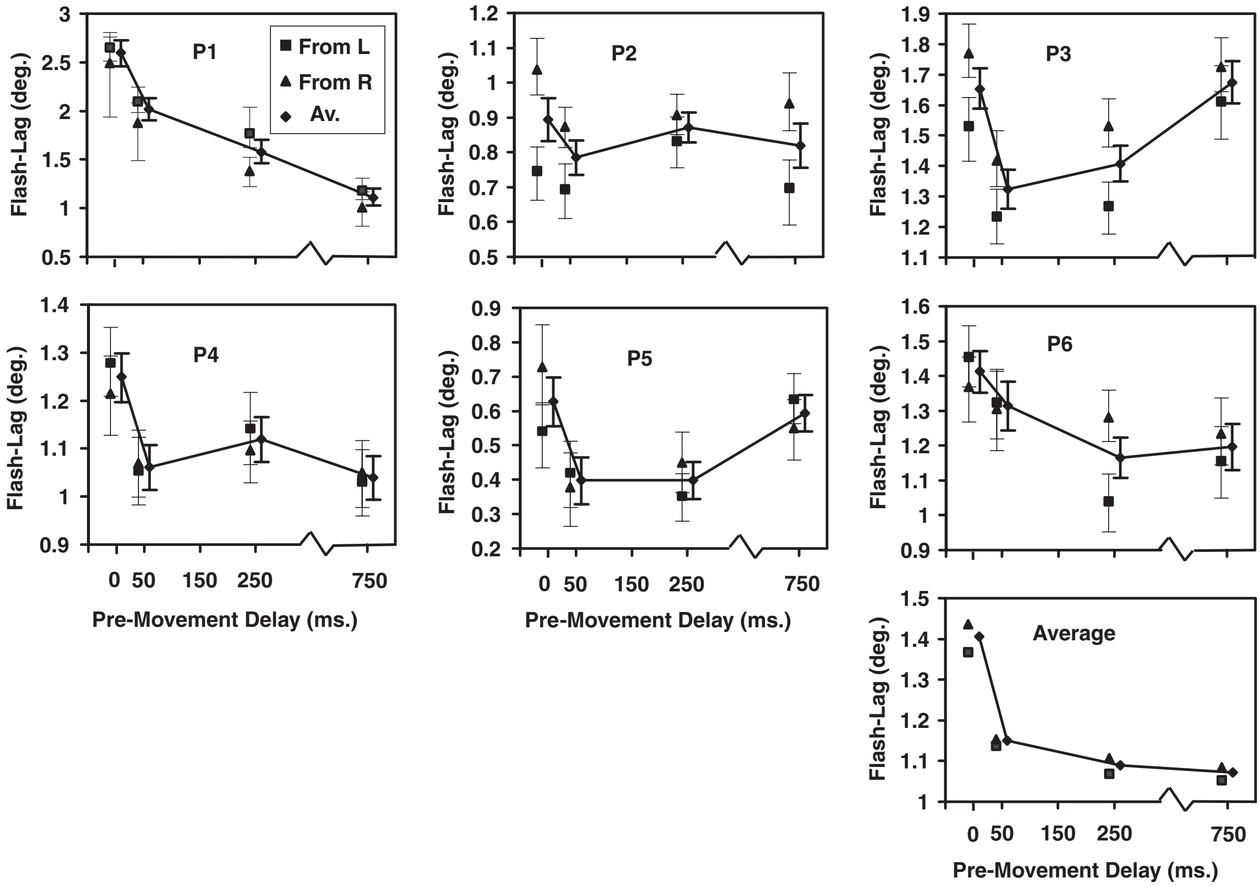

Fig. 2. Individual data, and means averaged across participants. All delays were 0, 50, 250, or 750 ms, but data points have been offset 10 ms in the graphs for clarity. Thin bars on the left, for each delay, show the data separately for motion from the left and from the right. Thick bars on the right are data collapsed across both directions (Av.). Error bars are 95% confidence intervals.

for 750 ms (only five out of six showed a reduction). The latter result may be due to problems with attention and/or eye movements in some participants.

4. Discussion

The consistent differences in flash-lag magnitude as a function of direction of travel of the moving object, observed in some of our participants, do not seem to have been reported elsewhere. In fact Whitney et al. (2000) stated that they found no such differences. Our data are most easily explained by a response bias in the naïve participants. They were often confronted by trials where the moving object and flash seemed to be perfectly aligned, yet they were required to make an unbiased guess. Some participants might have elected to, for example, just respond 'left' under these conditions of uncertainty. If they were doing this for trials involving movement from each direction, this would have the result of increasing their flash-lag effect for rightwards movement trials, and decreasing it for leftwards movement trials.

With regard to our main hypothesis, our data contradicts a strict form of any 'previous events are irrelevant' proposal. However, it seems to be consistent with the weaker assumption that the influence of pre-flash events is moderate. Postdiction could account for our data by assuming that the flash has not completely reset motion detectors (Eagleman & Sejnowski, 2000b). However, our experiment does not correspond to the conditions under which Eagleman and Sejnowski (2000b) proposed that this may happen—a low salience flash. Our flash was both larger and brighter than the moving object. If such graded resetting is allowed for all flash types, it is not clear how postdiction differs from Krekelberg and Lappe's (2000a) account of the flash-lag effect (described below). Our data is even more problematic for Brenner and Smeets' (2000) and Eagleman and Sejnowski's (2002) more recent proposal, where information is not just being discarded, but is assumed not to exist in the first place. If the flash is assumed to initiate the averaging of position information, and if we reasonably assume that this process cannot access positions occupied before the flash, then our data provides a direct falsification of Brenner and

Smeets' (2000) and Eagleman and Sejnowski's (2002) most recent proposal.

Before outlining our preferred interpretation of our data, we now consider an attentional account proposed by a reviewer. Steinman, Steinman, and Lehmkuhle (1995) investigated the line-motion-illusion—when a line is flashed some distance from, and slightly after, a cue flash, there is a perception of the line extending itself over time away from the fixation point. Their interpretation was that the cue flash focuses attention at that point, and attention then spreads outward along the line—closer parts of the line are processed more quickly. Steinman et al. (1995) varied the temporal offset between the two stimuli, and found the maximum illusion obtained (using a motion nulling technique), when the cue occurred 50 ms before the line. They concluded that maximal attentional focussing was achieved with this offset.

Applying this result to our paradigm would lead one to expect that the stationary 'to-be-moving' object would act as an attentional cue to the flash's appearance, thus shortening the processing time for the flash. In continuous versions of the flash-lag paradigm, one can indeed reduce the magnitude of the flash-lag effect by displaying the flash at a particular location at an earlier time. Thus one interpretation of our data would be that our precuing of the flash has allowed it to be processed faster, and hence have its position compared with that of the moving object earlier in the moving object's trajectory.

Although we cannot rule out some attentional contribution to our result, the above is problematic as an account of our results. Firstly, Steinman et al. (1995) and Hikosaka, Miyauchi, and Shimojo (1993) found that the facilitation provided by the flashed cue declined to about 50% of its maximal value, after about 250 ms lag, with stimulus parameters similar to ours. One would surely predict from these data that the magnitude of the flash-lag effect should be substantially restored for a length of presentation of 250 ms of our to-be-moving object (see Fig. 2). No such restoration is evident. Secondly, although time can be traded for space in a continuous flash-lag paradigm, Eagleman and Sejnowski (2000a) showed that giving the flash a temporal advantage of 53 ms in a flash-initiated paradigm did not affect the observed flash-lag effect at all. It is difficult to see why giving an explicit temporal advantage to the flash would have no effect in this case, while on the other hand our paradigm, supposedly giving the flash an advantage via a more subtle attentional mechanism, would have a substantial effect.

In any case, we would like to make the following point. Whether one favours this interpretation, or some other, does not change our main result—that events of the kind we have introduced before the flash do affect the magnitude of the flash-lag effect, in contradiction to the postdiction accounts.

The most parsimonious account of our data seems to us to be that there is a moving temporal window of integration which is averaged over to determine position, and it extends before the flash. This is Krekelberg and Lappe's (2000a) account of the flash-lag effect and they suggest that the window has a width of approximately 600 ms on the basis of fits to data. In our experiment, the stationary object in the first part of this temporal window will have weighted that position more highly than if no object were visible in that part of the window, thus giving a position estimate for the moving object which is closer to its starting position. As most accounts agree that we perceive the flash approximately 100 ms after it occurs, Krekelberg and Lappe's account can easily accommodate our data.

Another way of interpreting our data would be to say that we have decreased the Fröhlich effect—the invisibility of the beginning portion of the path of a suddenly appearing moving object. The moving object cannot be compared with the flash before the former becomes visible, and we have simply made it visible earlier. An experiment where participants put a pointer at the location of appearance of the moving object (cf. Müsseler, Stork, & Kerzel, 2002) could be conducted to verify this interpretation.

Our result contrasts with Whitney and Cavanagh's (2000) who found that pre-cuing had no effect on the magnitude of the flash-lag effect. It would appear that the gap of 30 ms in their experiment, between disappearance of the stationary object and its reappearance as a moving object, is critical. Krekelberg and Lappe's (2000a) model may well be able to account for this discrepancy—assuming that Whitney and Cavanagh's (2000) stationary cuing object is taken to be the same object as the moving one by the visual system, the temporal gap of 30 ms will still mean that for some of the window of integration there is no positional information, thus reducing the weighting for this position in the integration. This leads to a position estimate for the moving object which is further along its trajectory, and thus produces a relatively larger flash-lag effect than we obtained with no temporal gap at all. Future experimentation should investigate these matters by fixing the stationary object exposure to, say, 50 ms, and varying the time between its offset and later onset as a moving object between 0 and 30 ms.

However, whatever the results of these investigations, our challenge to postdiction will remain. We have unequivocally demonstrated that events before the flash do influence the size of the flash-lag effect, rendering the first version of postdiction difficult to defend, and the second untenable.

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